
Simulation and Comparison of Infra-Red Sensors for Automotive Collision Avoidance

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ABSTRACT

This paper presents a simulation and comparison of two different infra-red imaging systems in terms of their use in automotive collision avoidance applications. The first half of this study concerns the simulations of an "cooled" focal plane array infra-red imaging system, and an "uncooled" focal plane array infra-red imaging system. This is done using the United States Army's Tank-Automotive Command Thermal Image Model - (TTIM). Visual images of automobiles - as seen through a forward looking infra-red sensor - are generated, by using TTIM, under a variety of viewing range, and rain conditions. The second half of the study focuses on a comparison between the two simulated sensors. This comparison is undertaken from the standpoint of the ability of a human observer to detect potential (collision) targets, when seeing through the two different sensors. A measure of the target's detectability is derived for each sensor by using the United States Army's Tank-Automotive Research Development and Engineering Center Visual Model (TVM).

1. INTRODUCTION

Collision avoidance systems are seen as an integral part of the next generation of active automotive safety devices [1, 2]. Automotive manufacturers are evaluating a variety of imaging sensors for their usefulness in such systems [1]. Sensors that operate at wavelengths close to the human vision (such as video cameras) provide images that have good spatial resolution. However, the quality of the images (in terms of relative contrast

and spatial resolution) acquired by such a sensor degrades drastically under conditions of poor light, rain, fog, smoke, etc.. One way to overcome such poor conditions, is to choose an imaging sensor that operates at longer (than visual) wavelengths. The relative contrast in images acquired from such sensors do not degrade as drastically under poor visibility conditions. However, this characteristic comes at a cost; the spatial resolution of the image provided by such sensors is less than that provided by a video camera.

Passive infra-red sensors operate at a wavelength slightly longer than the visual spectrum.¹ Hence they perform better than a video camera (in terms of relative contrast) when the visibility conditions are poor. Also, since their wavelength of operation is only slightly longer, the quality of the image provided by an infra-red sensor is comparable to that of a video camera (in terms of spatial resolution). As a result, infra-red sensors have much potential for use in automotive collision avoidance systems [1, 3].

There are two state-of-the-art infra-red detectors, and they offer two alternatives when it comes to infra-red sensor system for automotive collision avoidance applications. The first alternative is based on a cooled focal plane array of infra-red detectors that operate in the 3 - 5 μ m wavelength. The second alternative is based on an uncooled focal plane array of infra-red sensors that operate in the 8 - 12 μ m wavelength. The first one provides images with better spatial resolution than the second. However, the cost of manufacturing and operating such a sensor system is more than the second one.

The TACOM Thermal Image Model (TTIM) is a

¹The visual spectrum is between 0.4 - 0.7 μ m, where as the infra-red spectrum is between 0.7 - 12 μ m

† THIS WORK WAS SUPPORTED IN PART BY THE UNITED STATES ARMY RESEARCH OFFICE UNDER CONTRACT DAAL03-91-C-0034

computer model that simulates the appearance of a thermal scene as seen through infra-red imaging system [6]. TTIM can simulate the sampling effects of the older single detector scanning systems, as well as more modern systems that use focal plane staring arrays. TTIM can also model image intensifiers. A typical TTIM simulation incorporates the effects of atmospheric conditions on the image, and it is accomplished by using LOWTRAN - a computer model of the effects of atmosphere conditions on thermal radiation that was developed at the United States Air Force's Geophysics Laboratory. A particularly attractive feature of TTIM is that it produces a simulated image for the viewer, not a set of numbers as some of the other simulations do. We refer the reader to Fig. 1 for schematic representation of TTIM.

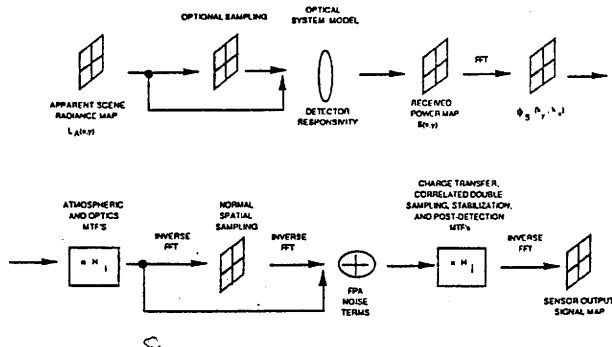


Figure 1: Schematic representation of TTIM

In the first half of this paper we use TTIM to simulate the cooled and uncooled infra-red imaging systems, and compare their performance from the standpoint of automotive collision avoidance applications. Analogous comparisons exist in current literature (see [4, 5] for example). However, it is our opinion that such studies are not applicable for the situation at hand. TTIM allows us to compare the performance of the two infra-red systems in terms of how good is the quality of their images for subsequent human perception/interpretation. The existing studies do not allow such comparisons.

The comparison of system performance leads us to the second half of this paper. Given that we have two images of the same scene, captured by using the two different infra-red systems, we use TVM to assess which of the two is "better". TVM is a computational model of the human visual system [7]. The model consists of two parts: the first part is a color separation module, and the second part is a spatial frequency decomposi-

tion module. The color separation module is akin to the human visual system. The spatial frequency decomposition system is based on a Gaussian-Laplacian pyramid framework. Such pyramids are special cases of wavelet pyramids, and they represent a reasonable model of spatio-frequency channels in early human vision [8]. We refer the reader to Fig. 2 for a schematic representation. of TVM.

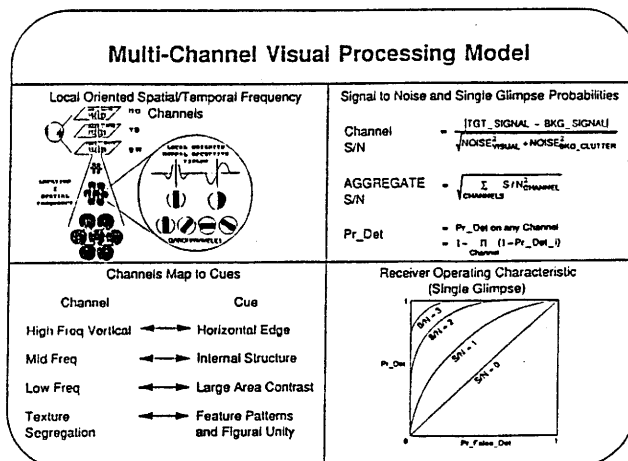


Figure 2: Schematic representation of TVM

Given two images of the same scene, an object of interest, and the background, we use TVM to produce a measure of detectability for the object in each of the images. The image in which the object has measure of detection is the "better" one among the two.

2. SIMULATION OF INFRA-RED SENSORS

This section presents the simulation of cooled and uncooled infra-red imaging systems using TTIM. Specifically, we generate (simulated) images of commercial vehicles in a typical road scene as seen through such infra-red systems using TTIM. We present examples of how viewing range and rain affects the quality of the acquired image.

We see this simulation as a substantial first step, and as providing a means to comprehensively evaluate and compare the two sensor systems in the near future. Our ability to simulate the sensors provides a means for exactly repeating imaging experiments and measurements, something that is difficult to achieve in field trials. Also based on our experience, the ability to simulate the sensors provides us with the ability to exercise precise control over the imaging conditions. In the cooled infra-red systems, for example, it is important to provide proper temperature shielding (and control) during field trials. Otherwise, the quality of

the images acquired from the infra-red system is badly affected, and it negatively impacts the validity of subsequent comparisons between sensor systems. By simulating cooled infra-red systems we can overcome such difficulties.

In Figs. 6 and 7 we present (simulated) images of typical commercial vehicles when the viewing distance (the distance between the vehicle and the sensor) increases. This done for both the cooled and uncooled cases, by inputting into TTIM the thermal image in Fig. 3.

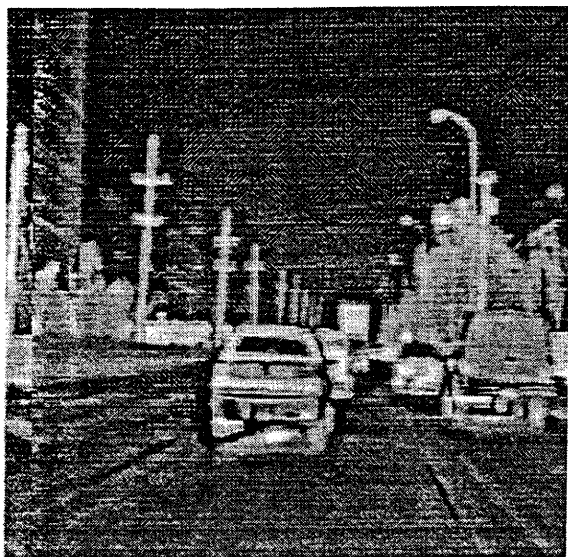


Figure 3: Input image to TTIM

In Figs. 8 and 9 we present (simulated) images of the same set of vehicle when the viewing distance is fixed, but when the amount of rain fall under which the image is acquired increases.

3. SENSOR COMPARISON

In this section we use TVM to compare the quality of images acquired from the cooled and the uncooled infra-red imaging systems. Specifically, we input into TVM two (simulated) images, corresponding to the two infra-red systems. Then, using TVM we obtain a measure of detectability in each of the images for a vehicle of interest.

The detectability measure obtained from TVM is the signal-to-noise ratio (SNR) between the vehicle of interest and the background (as explained in Fig. 2). In Fig. 4 we plot this SNR for both cooled and uncooled systems as a function of spatial frequency.

Next, in Fig. 5 we plot the SNR for both systems (actually the maximum SNR among the different frequency channels) when the amount rain fall under which the image is acquired increases.

4. CONCLUSIONS

In this paper we provided a simulation of and a comparison between cooled and uncooled infra-red imaging systems. This was done with a view towards using such systems for automotive collision avoidance applications. Using TTIM, we successfully simulated both the infra-red imaging systems. We provided (simulated) images as seen through these sensors, when the viewing distance changes and when the amount of rain-fall under which the images are acquired increases. Next, by using the TVM we compare the two sensors. In each of the spatial frequency channels found in early vision among humans, we obtain a measure of detectability (in terms of SNRs) for an object and background interest. We plot the SNR versus spatial frequency for both the sensors, and obtain the variation in the SNR as the amount of rain fall under which the images are acquired increases. Sensor comparisons, are just but one aspect of collision avoidance. There are a number of other human factors and social issues as well associated with the "science of collision avoidance" as pointed out in [2].

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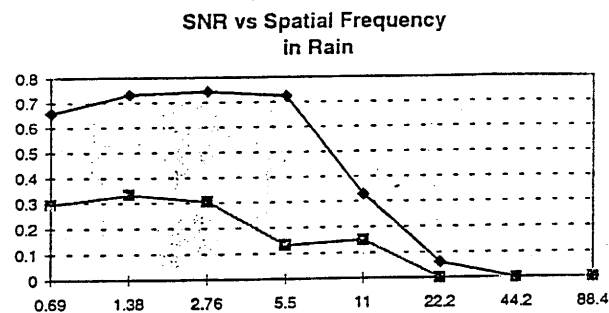


Figure 4: SNR versus spatial frequency

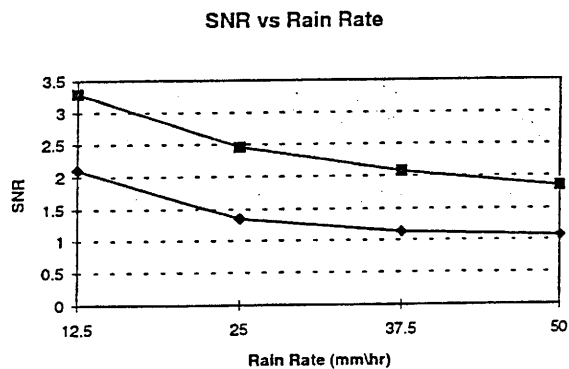


Figure 5: SNR versus rain fall amount

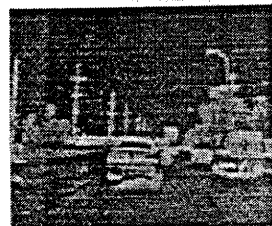
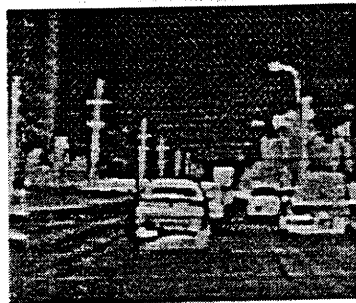
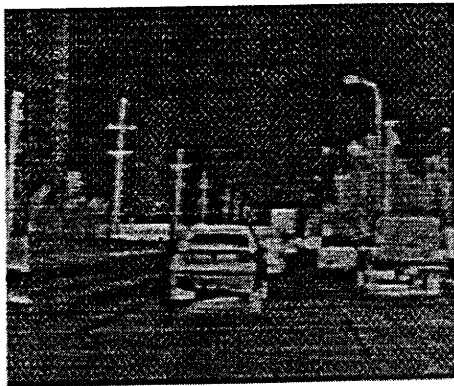


Figure 6: Simulation of the effects of viewing distance on spatial resolution in images acquired via cooled infra-red imaging systems - 70m, 90m, 120m, 150m (Top to Bottom)

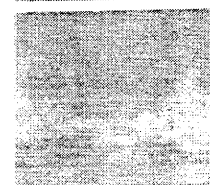
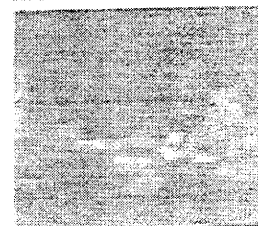
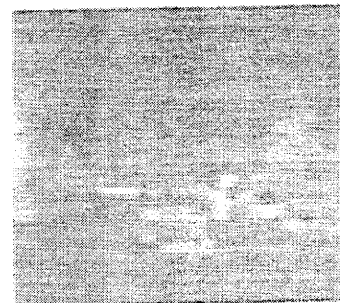
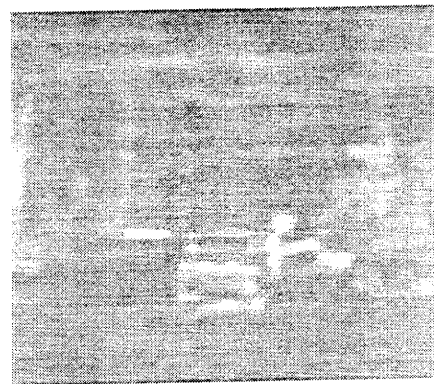


Figure 7: Simulation of the effects of viewing distance on spatial resolution in images acquired via uncooled infra-red imaging systems - 70m, 90m, 120m, 150m (Top to Bottom)

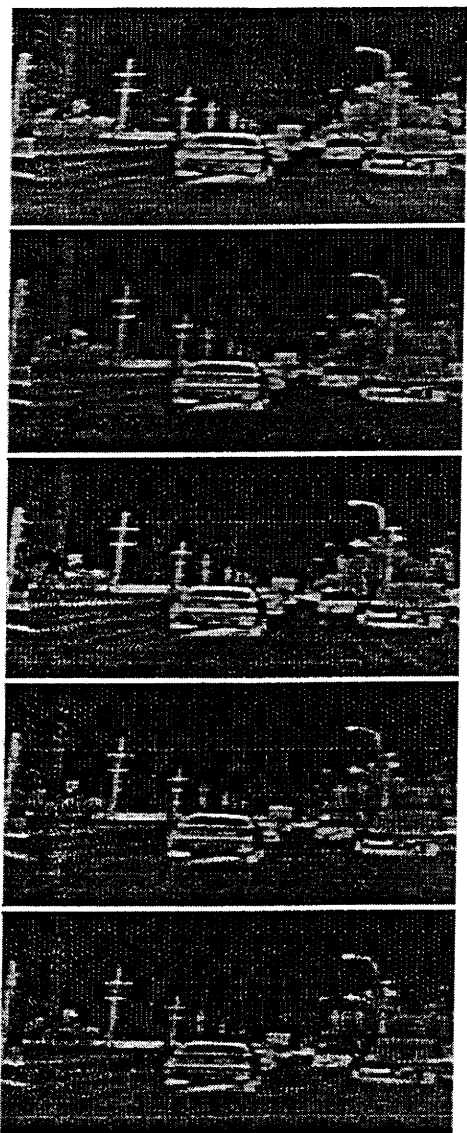


Figure 8: Simulation of the effects of rain fall on relative contrast in images acquired via cooled infra-red imaging systems - 0mm/hr, 12.5mm/hr, 25mm/hr, 37.5 mm/hr, 50mm/hr (Top to Bottom)

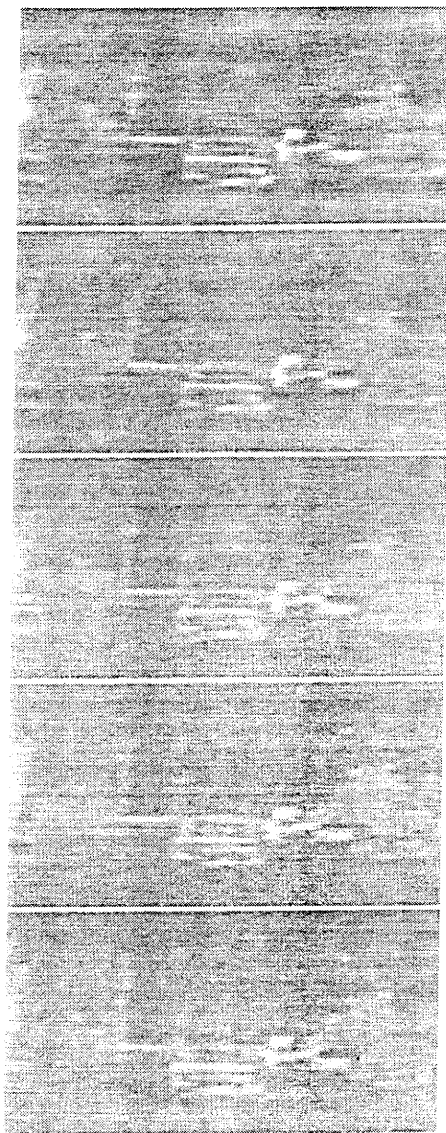


Figure 9: Simulation of the effects of rain fall on relative contrast in images acquired via uncooled infra-red imaging systems - 0mm/hr, 12.5mm/hr, 25mm/hr, 37.5 mm/hr, 50mm/hr (Top to Bottom)